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Design-Drivers of Hybrid Mission Scenarios: Effects on Unmanned Aerial Vehicle Design and Mission Management

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Abstract: Herbst S and Klöckner A. (2014). Design-drivers of hybrid mission scenarios: Effects on unmanned aerial vehicle design and mission management. *International Journal of Unmanned Systems Engineering*. ***2***(3): 45-60. Motivated by rapid progress in sensor development, companies, organizations, and government authorities show growing interest in versatile unmanned aerial vehicles for increasingly complex and integrated tasks in civil conditions. In order to evaluate and compare research in context of missions with hybrid flight speed requirements, we introduce two benchmark scenarios based on civil search and rescue operations in mountainous areas. The scenarios contain different challenges like the identification of multiple persons in a narrow area in winter (buried avalanche victims) and the identification of a single person in a wide area in summer (missing paraglider). Both incidents take place in the European Alps with current standard infrastructure provided. In addition, we illustrate detailed settings of the scenarios and sources for terrain (shuttle radar topography mission data, SRTM3) and all required airspace and weather data. The missions are introduced as benchmark for research groups dealing with single components, overall configurations, or any other aspect of unmanned aerial vehicles. We exemplarily show how to use the scenarios for unmanned aerial vehicle design and mission management applications.

Keywords:
Aircraft design
Design-driver
Mission management
Mission requirements
UAS

I. Introduction

The progress in developing payload electronics for unmanned aircraft systems (UAS) continuously creates a variety of new possible applications [1]. New mission scenarios require capabilities from different source applications, which are partially contradicting and currently cannot be achieved by a single UAS. Therefore, these *hybrid* mission scenarios lead to various fields of UAS research, such as aircraft and system design, sensor development, mission and trajectory planning, mission and fleet management, as well as control system development. Most of

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these fields lack possibilities to compare or evaluate research results.

To close this gap, two dedicated civil scenarios with corresponding missions are proposed. They are provided to the community as initial problem definitions with sufficient degree of detail to immediately start working on solutions and criteria for evaluation and comparison of the results. The scenarios are free to be extended with necessary definitions for any field of research. The different parts of the scenario definitions are modular to a degree that allows realizing different levels of detail and challenge. A user can decide freely which parts of the scenarios shall be implemented or modified and how to solve the contained problems for the specific research objective at hand. An entire collection of all necessary information for implementing the scenarios is presented in the Appendix. Sources for detailed information on terrain and weather data are also provided.

A typical application for the proposed mission scenarios is designing unmanned aircraft specifically for a given range of achievable missions. Regarding this, the causal dependencies between scenario, mission requirements and aircraft design are considered. Further fields of application include reactive mission planning [2], managing manned-unmanned teaming fleets [3] and designing control systems, which are robust to adverse environmental conditions [4].

II. Scenarios for Benchmarking UAS Research

The benchmarks are embedded in the general setting of Search-And-Rescue (SAR) operations in the European Alps. Deploying UAS in this setting is expected to increase the overall rescue performance by enhancing situational awareness [5] and by facilitating job-sharing between helicopter crews and UAS operating personnel. Since current UAS are not able to rescue persons in distress, the UAS's task is reduced to a Search-And-Mark (SAM) operation. In both scenarios, missing persons have to be found and their locations have to be reported to the ground control station. Both scenarios are chosen in order to cover different mission ranges, operation times, sensor and terrain requirements, as well as environmental conditions.

The presented scenarios can be implemented without serious changes to the existing rescue operations, infrastructure, and airspace regulations. In order to fly in non-segregated airspace and operate successfully in mountainous areas, the UAS will need sense-and-avoid capability for air and ground obstacles. A continuous data link from the ground control station to the aircraft is demanded for command, control, and communication. Additionally, the characteristic of mountainous SAR missions demands ability for an extreme short take-off and landing (ESTOL) or preferably vertical take-off and landing (VTOL).

A. Scenario 1: Buried avalanche victims

A realistic scenario for future unmanned aerial vehicles is the search for avalanche victims. The main challenge of this scenario is time pressure. Fig. 1 shows the survival probability of avalanche victims as a function of time [6]. After 30 minutes the survival probability decreases to 50%. After two hours, the probability to recover a victim alive is only marginal. Thus, this setting requires an aircraft with fast climb and cruise flight performance. In addition, a slow loitering speed during the search pattern is also essential [7].

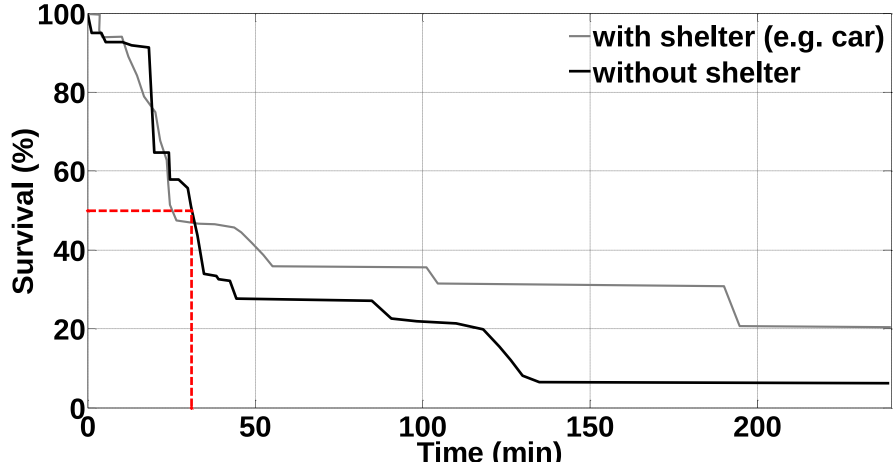

Fig. 1: Avalanche survival probability [6]

Infrastructure, Flight Area and Terrain

The underlying infrastructure is typical for European alpine regions: A hospital and the associated heliport for manned air rescue are located in a medium-sized town in a valley at altitudes between 400 m and 1000 m above mean sea level (AMSL). An airfield with UAS for search and reconnaissance tasks will be located next to the heliport in order to immediately respond to emergency calls. The UAS will need to cover the same mission radius as manned SAR helicopters of up to 70 km [8,9]. In alpine regions the terrain is mountainous with peaks up to 4500 m and corresponding severe weather conditions. The airspace may be segmented airspace class D [10]. For lower levels of challenge, these specifications may be reduced as outlined in Table 1. Detailed terrain information is provided in the Appendix, based on the Shuttle Radar Topography Mission (SRTM3) [11].

Table 1: Flight area and terrain

Challenge	Min	Max
Altitude airfield	400 m	1500 m
Altitude search site	1800 m	4500 m
Altitude mountain peaks	2000 m	4500 m
Mission radius	10 km	70 km
Airspace	Restricted	D

Environmental Conditions

Avalanche incidents in the European Alps typically occur from late autumn to late spring[12]. At altitudes higher than 3500 m they can also occur during summer [13]. Incidents are most likely to occur in the morning, because mountaineers typically restrict their tours to these times to minimize the avalanche risk. Depending on the time of the year, temperatures as low as -20°C may be expected. Heavy cloud coverage, snow, and wind may be considered additional challenges. Basic information about weather and time are compiled for different levels of difficulty in Table 2.

More detailed weather information can be obtained from the COSMO database [14]. The cloud coverage definition ranges from cloudless (0/8) to total clouded (8/8).

Table 2: Weather conditions

Challenge	Min	Max
Date	31th August	1st March
Daytime	05:30	08:30
Temperature Valley	5 °C	-7 °C
Temperature Peak	-9 °C	-20 °C
Precipitation Valley	None	Snow
Precipitation Peak	None	Heavy snow
Wind Valley	0 m/s	5 m/s
Wind Peak	0 m/s	20 m/s
Gusts Valley	None	2 m/s
Gusts Peak	None	6 m/s
Thermals	None	8 m/s
Flight Visibility	30 km	5 km
Clouds	None	7/8
Cloud Base	-	5200 m

Incidence Description

A group of three to ten mountaineers reports an avalanche with one or two victims buried under the avalanche close to a mountain peak. The emergency call indicates the avalanche location only with a limited accuracy of up to 2 km because of imprecise measurements and the reporters' anxiety. The size of the avalanche may also vary from 0.25 km^2 to 1 km^2 as detailed in Table 3.

Table 3: Incidence description

Challenge	Min	Max
Number of victims	1	2
Avalanche location accuracy	10 m	2 km
Avalanche area	0.25 km^2	1 km^2
Number of rescuers	1	8

Task Description

Within the SAR mission, the UAS conducts a SAM mission. This requires collaboration between the UAS, the manned helicopter crew, professional rescue personnel, and the mountaineers on the ground. The UAS is used to enhance situational awareness by detecting and locating the avalanche with the buried victims and by communicating their location to all involved parties. To enhance survivability, this task has to be accomplished as soon as possible and, if procurable, within 30 min after the incidence report. A detailed scenario setting description is implemented in Appendices C and D. The corresponding mission is analyzed in Appendix E.

B. Scenario 2: Missing paraglider

The second benchmark scenario for UAS search tasks is a missing paraglider. This scenario is not as time critical as the avalanche setting. Its main challenge is a wide search area combined with a fast search process. The setting, thus, requires a fast cruise flight combined with an effective climb performance and a long endurance search performance.

Infrastructure, Flight Area and Terrain

The infrastructure is the same as in the avalanche scenario. In contrast to scenario 1, the region is more urban with more spacious valleys. The airspace can be segmented in class C and D [10]. Table 4 summarizes the mission specifications for the missing paraglider scenario.

Table 4: Flight area and terrain

Challenge	Min	Max
Altitude airfield	400 m	800 m
Altitude search site	1000 m	3000 m
Altitude mountain peaks	2000 m	4500 m
Mission radius	10 km	70 km
Airspace	Restricted	C, D

Environmental Conditions

Generally, paragliders fly during the whole year but the main season for long distance flights is from the end of March until the end of September. Specifically, days with many sunshine hours and mid-level clouds at high cloud bases offer best conditions. Especially at noon, experienced pilots use the strong thermals to fly long distances over unoccupied areas. Since pilots typically do not fly in groups and paragliders must not hand in a flight plan, crashes are often communicated very late. Therefore, in most cases SAR missions start in the late afternoon or evening. Rain, wind, and total cloud coverage (8/8) may pose additional challenges. Weather and time information is summarized in Table 5.

Table 5: Weather conditions

Challenge	Min	Max
Date	1st August	31st May
Daytime	16:00	21:30
Temperature Valley	22 °C	15 °C
Temperature Peak	11 °C	4 °C
Precipitation Valley	None	Drizzle
Precipitation Peak	None	Medium rain
Wind Valley	0 m/s	4 m/s
Wind Peak	0 m/s	15 m/s
Gusts Valley	None	3 m/s
Gusts Peak	None	11 m/s
Thermals	4 m/s	none
Flight Visibility	40 km	5 km
Clouds	3/8	8/8
Cloud Base	3900 m	3500 m

Incidence Description

At the end of a day with very good thermal conditions, a missing paraglider is reported. Another paraglider is able to describe his destination and a position where he was last seen. The crash site can be located in a mountainous region of up to 3000 m altitude and is narrowed down to an area of up to 5 km x 7 km. Different ground covers and small visible parachute cross-sections as low as 1 m² can be considered. Different levels of difficulty are presented in Table 6.

Table 6: Incidence description

Challenge	Min	Max
Number of victims	1	1
Search area	2 km x 3 km	5 km x 7 km
Ground cover	Grass and rocks	Grass, forest, rocks, snow and ice
Visible parachute cross section area	5 m^2	1 m^2

Task Description

Similar to the avalanche rescue mission, the UAS needs to perform a SAM mission in order to support the manned SAR mission. Collaboration between the UAS and the manned helicopter crew is essential. The UAS must search and detect the victim, in order to enhance the capabilities of the manned SAR helicopters for rescue and medical treatment of accident victims. Additionally, the UAS must ensure the victim is informed that he was found. This psychological task is very important to increase the acceptance of the technical system. A detailed scenario implementation and mission analysis is presented in Appendices A-H.

III. Identification of UAV Design-Drivers

The proposed scenarios can be used to derive requirements for UAV design. Applying the top-down method for identification of UAV design-drivers differs to common manned aircrafts, because the payload fraction is much higher. Therefore, it is essential to include its requirements and effects on the aircraft in the conceptual design phase. The identification of design drivers starts with the task derived from the scenario as well as related sensor requirements, and ends with defined UAV requirements. In case of electro optical sensors, such as cameras, the Johnson criterion [15] is used to determine the influence of sensor technology on the mission, aircraft requirements and finally aircraft performance. By modifications in the Johnson criterion, design-drivers of sensor data on aircraft requirements are determined. Sensor technology parameters considered include focal distance, resolution, sensor size, power demand and mass. Fig. 2 displays the general method for the identification process with a few selected parameters. The presented influences results from an increase of the initial property. An increasing difference in mountain altitude require a larger focal distance for a higher flight altitude in order to reduce fuel weight. In contrast, it also results in a higher payload weight.

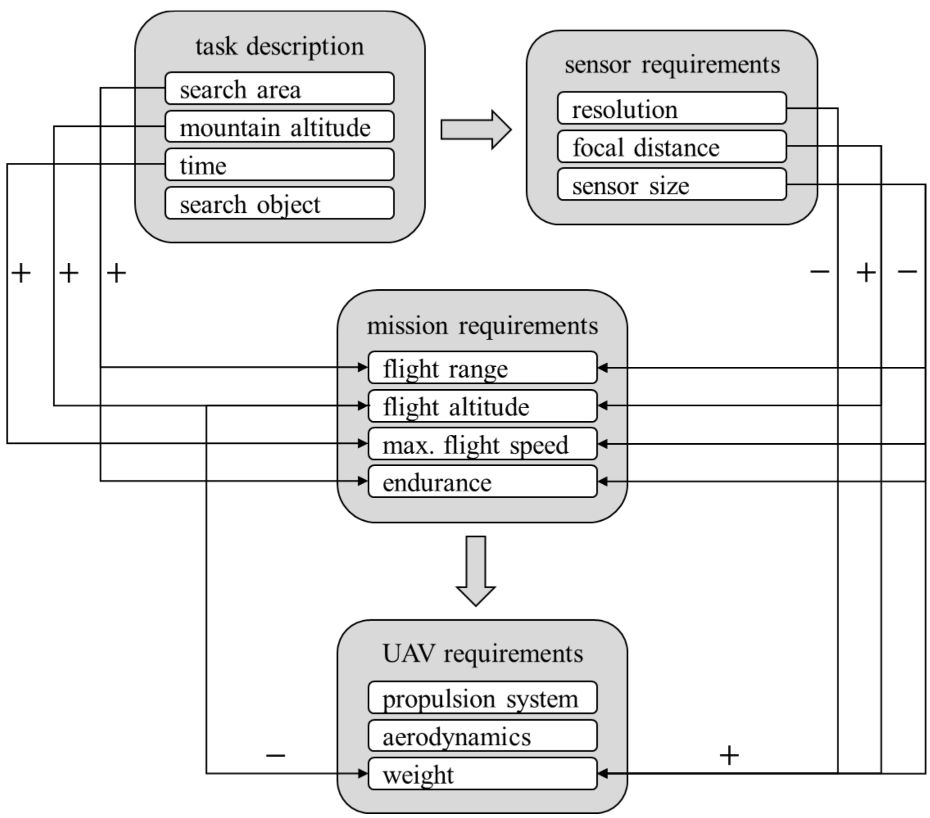

Fig. 2: Identification of UAV design requirements

The detailed influence of sensor resolution on flight range is shown in Fig. 3. High resolution sensors decrease the mandatory flight range immensely. An increase in pixel number from 2.3 Mio to 23 Mio minimizes the flight range by more than 75%. However, payload weight increases with resolution, resulting in either a loss of possible fuel weight or of endurance and flight range. Therefore, a tradeoff must be enforced. In addition to the mentioned payload requirements, flight speed and range, as well as take-off and landing capabilities are important design drivers in the proposed hybrid missions.

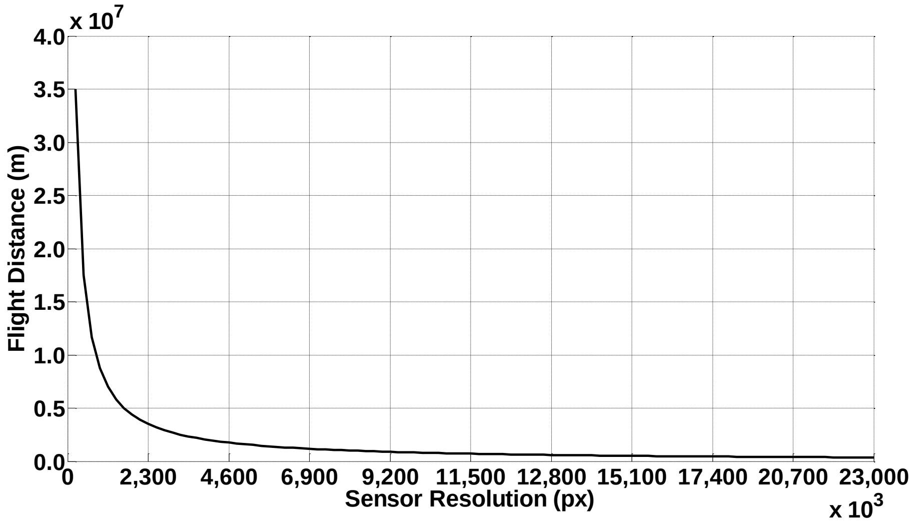

Fig. 3: Flight Range in a search pattern (area size: 5 km x 7 km)

The objected design should have a minimum take-off weight for a maximum reconnaissance performance which is related to the potential flight and rescue capacities of the manned SAR helicopters.

IV. Effects on Unmanned Aerial Vehicle Design

Considering the identified design-drivers, the aircraft's appearance differs from conventional fixed or rotary wing configurations: Because of the VTOL and hybrid flight speed requirements (hovering – fast cruise) as well as capability of long endurance at altitudes up to 5000 m (Table C1 in the Appendix) a novel aircraft concept is needed. Existing configurations with movable wing or propulsion system are not able to fulfil such diverse and advanced demands. Therefore, research in different energy storage and engine types which can manage short-term high peak power and long-term cruise power is needed. Fig. 4 displays exemplary peak power demands at hovering together with take-off and landing. The lines of the axial climb, hovering, and cruise at stall speed limit look like one line, because they are very close together. Comparing at attained turn rate (ATR) limit, the peak power demand is nearly ten times higher than at maximum flight speed. Also, the specific excess power (SEP) limit and the sustained turn rate (STR) limit require less power. In order to accomplish the endurance and flight range objectives, a tradeoff regarding an increase in sensor performance with corresponding mass and power demand penalties is required. Moreover, enhanced sensor and communication system capabilities for airspace integration demand attention. For those reasons, new aerodynamic designs, light weight structures and stability issues need to be considered. Taking into account all those aspects an extended iterative conceptual design process can be achieved.

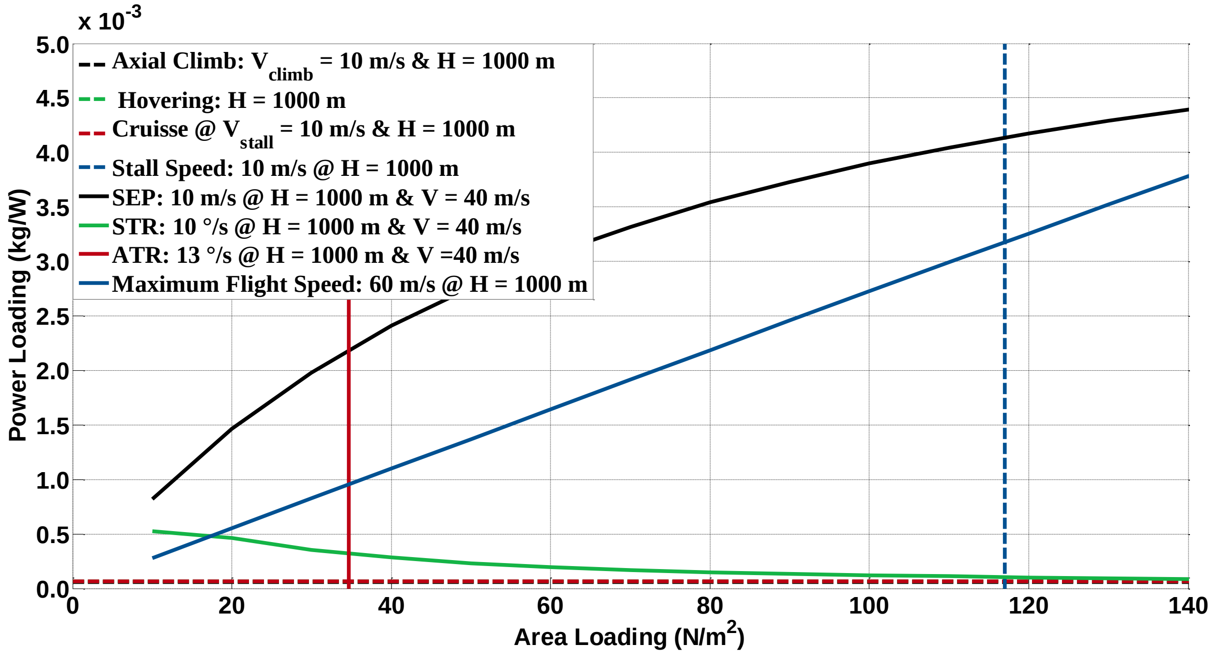

Fig. 4: VTOL unmanned aircraft design chart

V. Effects on Mission management

Assuming an aircraft has been designed as described above, the vehicle must be enabled to automatically achieve the mission goals. This is the purpose of a mission planning and management system to be implemented on board the aircraft or in the ground control station. To this end, the overall mission must be broken down into smaller tasks and activities. The missions described in this paper require tasks from the domains of locomotion (e.g., take-off, cruise, land, sense and avoid), search (pattern flying, recognition of objects), and communication (with the ground station, other crew, and the victims). If a single vehicle cannot perform all of these tasks, they must be split between several vehicles, resulting in a cooperative mission. The present missions might, for example, require a communication relay above the mountains for communication with the ground station.

Behavior trees allow to modularly combine skills of UASs [2]. Fig. 5 shows mission plans for a communication relay [16] and the actual SAM aircraft using the BehaviorTrees library [17].

VI. Conclusions and Outlook

Two different hybrid UAS scenarios are proposed as benchmarks for different applications in UAS research. Using the top-down method to identify the UAS design-drivers leads to a relationship of sensor resolution and required flight range. Because of the high payload fraction, it is necessary to focus on payload sensitivities onto conceptual aircraft design process very early. Designing the propulsion system is one of the main challenges, because of large differences in power demand for various mission phases. Also, an efficiency comparison, whether one high performance or several low performance UAVs are able to accomplish the mission, can be performed. The scenarios may also be used to design and evaluate reactive mission plans.

VII. Acknowledgment

Many thanks to Christian Keil for pointing us to the COSMO weather data.

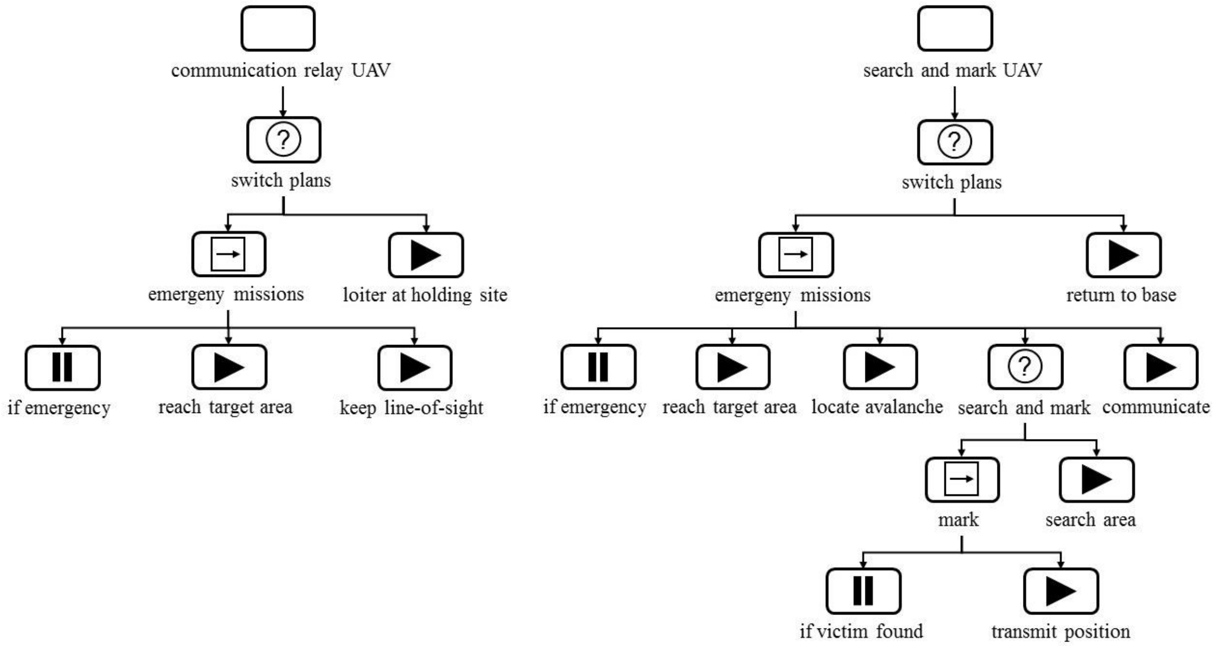

Fig. 5: Exemplary mission plans using behavior tree notation

VIII. REFERENCES

1. **Nehme CE, Cummings ML** and **Crandall J**. (2006). *A UAV mission hierarchy*. Humans and Automation Laboratory. Massachusetts Institute of Technology. Boston. USA. crossref
2. **Klöckner A**. (2013). *Behavior trees for UAV mission management*. In INFORMATIK 2013: Informatik angepasst an Mensch, Organisation und Umwelt. Koblenz. Germany. crossref
3. **Talley D, Schellpfeffer N, Johnson C** and **Mavris D**. (2004). *Methodology for the mission requirement determination and conceptual design of a morphing UCAV*. In AIAA 3rd Unmanned Unlimited. Chicago. Illinois. crossref
4. **AlSwailem SI**. (2004). *Application of robust control in unmanned vehicle flight control system design.* PhD Thesis. Cranfield College of Aeronautics. Cranfield University. Cranfield. crossref
5. **Paul T** and **Brämer E**. (2013). Operational considerations for teaming manned and unmanned helicopter. *Journal of Intelligent and Robotic Systems*. ***69***(1-4): 33–40. crossref
6. **Brugger H, Durrer B, Adler-Kastner L, Falk M** and **Tschirky F**. (2001). Field management of avalanche victims. *Resuscitation.* ***51***(1): 7-15. crossref
7. **Meiboom M, Andert F, Batzendorfer S, Schulz H, Inninger W** and **Rieser A**. (2013). Untersuchungen zum Einsatz von UAVs bei der Lawinenrettung. *German Aerospace Congress.* Vol. 62. Stuttgart. Germany. crossref
8. **Rega.** (2013). *Helicopter bases – Swiss Air-Rescue Rega – Emergency number 1414.* Available: http://www.rega.ch/en/operations/helicopter-bases.aspx. [Accessed 21st May 2013]. crossref
9. **Wolfsfellner W**. (2011). *ADAC-Stationsatlas "Christoph - bitte kommen!"* Ausgabe 2011/2012: Luftrettungsstationen. (6th ed.). Wolfsfellner. München. crossref
10. **Gregorius J**. (2014). *European Airspaces DFC Saar*. Available: http://www.dfc-saar.de/. [Accessed 2nd May 2014]. crossref
11. **National Geospatial-Intelligence Agency**. (2014). *SRTM3 Data, Version 2 Eurasia*. Available: http://dds.cr.usgs.gov/srtm/version2_1/SRTM3/Eurasia/. [Accessed 21st May 2014]. crossref
12. **Mair R** and **Nairz P**. (2010). *Lawine*. Innsbruck. Wien. crossref
13. **Willsher K, Beaumont P** and **Douglas E**. (2012). Mont Blanc avalanche kills nine climbers. Available at: http://www.theguardian.com/world/2012/jul/12/mont-blanc-avalanche-kills-climbers1 (Accessed 20th May 2014). crossref

14. **Baldauf M, Seifert A, Förstner J, Majewski D, Raschendorfer M** and **Reinhardt T**. (2011). Operational convective-scale numerical weather prediction with the COSMO model: Description and sensitivities. *Monthly Weather Review*. ***139***: 3887–3905. crossref
15. **Johnson J**. (1958). Analysis of image forming systems. *Image Intensifier Symposium.* Fort Belvoir, VA. crossref
16. **Klöckner A, Leitner M, Schlabe D** and **Looye G**. (2013). *Integrated modelling of an unmanned high-altitude solar-powered aircraft for control law design analysis.* Advances in Aerospace Guidance Navigation and Control - Selected Papers of the Second CEAS Specialist Conference on Guidance, Navigation and Control. Berlin Heidelberg. Springer. Pp. 535-548. crossref
17. **Klöckner A**. (2014). The Modelica BehaviorTrees Library: Mission planning in continuous-time for unmanned aircraft. *Proceedings of the 10th International Modelica Conference.* Lund. Sweden. crossref

IX. Notation

ATR	Attained turn rate
SAM	Search and mark
SAR	Search and rescue
SEP	Specific Excess Power
SRTM3	Shuttle Radar Topography Mission
STR	Sustained turn rate
UAS	Unmanned aerial system
UAV	Unmanned aerial vehicle
VTOL	Vertical take-off and landing

X. Appendix

C. Scenario 1: Detailed implementation

The avalanche rescue mission takes place in the French Alps, in the region of Mont Blanc. Mountaineers on their way to the peak of Mont Maudit reported an avalanche descent at the northern side of the mountain.

Avalanche location: Mount Maudit (northern side); underneath the peak

45° 51’ 08.94’’ N
6° 52’ 38.59’’ E

By reason of high inclination, Fig. A1 visualizes the avalanche area with SRTM3 data [11]. It is eminently advantageous to use an UAS in order to protect the rescue personnel on the ground. It can be assumed that the infrastructure is located in the town Chamonix and is close to the area of incidence. The coordinates of the approximately used airfield can be estimated as:

Location airfield: 45° 56’ 24.17’’ N
6° 53’ 52.87’’ E

In order to react quickly on emergencies and reduce flight time, the hospital and the heliport are close to the airfield. The hospital is located in the west of Chamonix within a range of 4 km and the heliport is directly neighbouring. In order to get to the incident area the following airspaces are momentarily active and needed to receive attention:

- R30B interdit PUL (GND – FL115), restricted
- D (FL115 – FL195) [10]

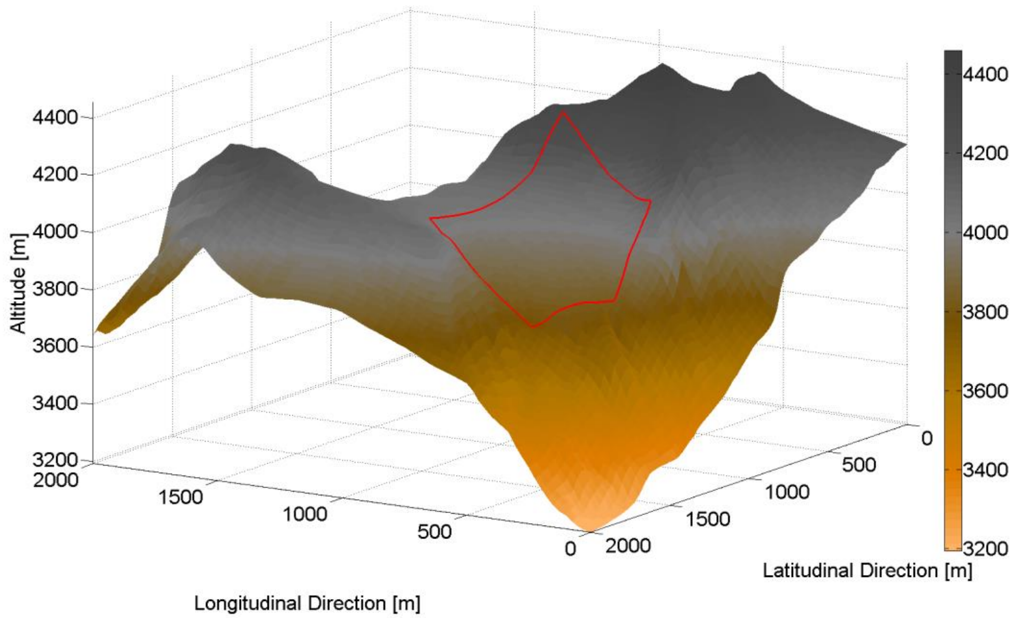

Fig. A1: Mountain side of the avalanche [11]

In Fig. A2 airspace R30B is visualized in yellow and airspace D is marked in blue. The avalanche area is tagged red in the middle of the area. It is located above airspace D. The airfield is also visualized in red and is located in the north of the area (middle left).

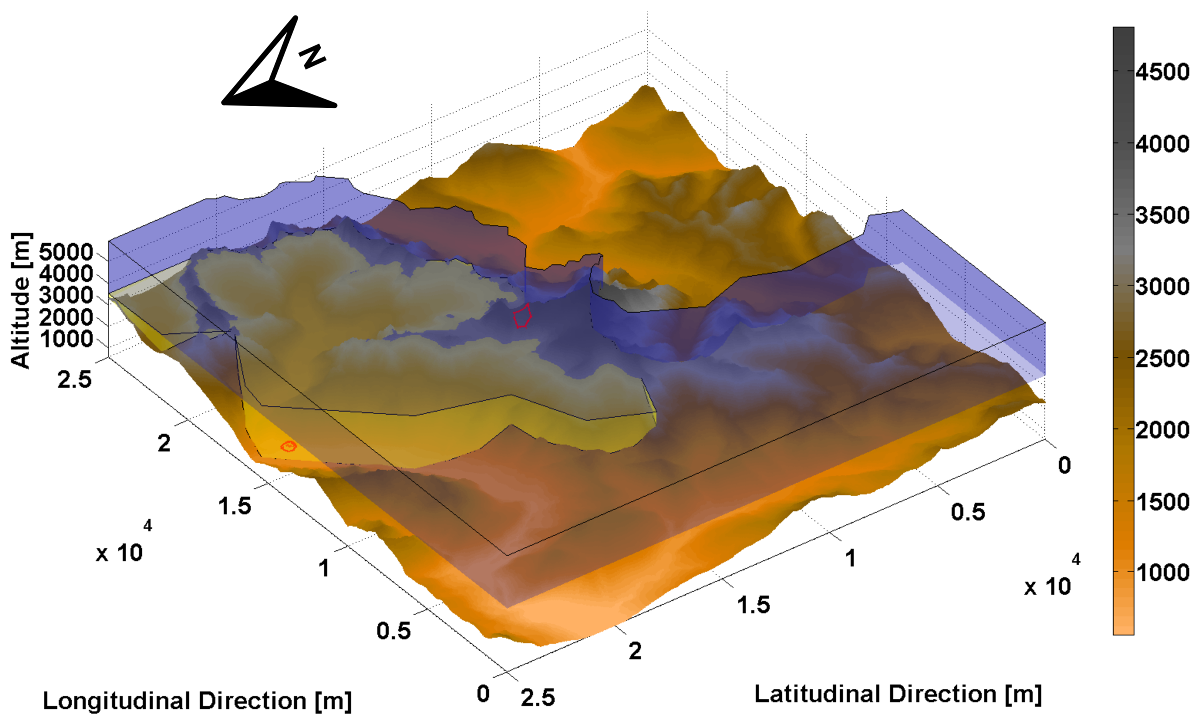

Fig. A2: Flight area with airspaces [10, 11]

D. Scenario 1: Final scenario information

The essential information for verifying a problem-solving approach for this scenario is the coordinates of the avalanche corner points, the buried victims, and the mountaineers (Fig. B1).

CP1:	45° 51' 26.02'' N 6° 52' 24.54'' E
CP2:	45° 51' 23.14'' N 6° 52' 41.63'' E
CP3:	45° 51' 18.65'' N 6° 52' 50.10'' E
CP4:	45° 50' 57.91'' N 6° 52' 44.09'' E
CP5:	45° 51' 5.20'' N 6° 52' 21.14'' E
CP6:	45° 51' 18.24'' N 6° 52' 16.12'' E
Victim 1 (red):	45° 51' 14.88'' N 6° 52' 25.00'' E
Victim 2 (red):	45° 51' 23.98'' N 6° 52' 26.75'' E
Mountaineers (green):	45° 51' 2.69'' N 6° 52' 22.53'' E

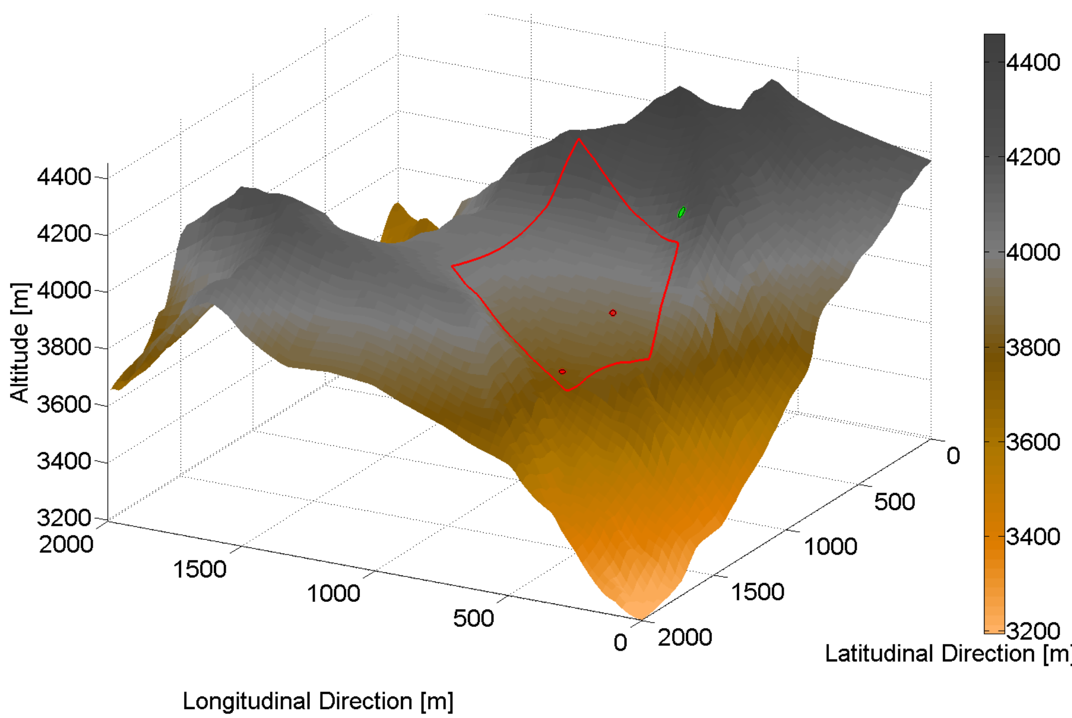

Fig. B1: Mountain side of the avalanche with victims and mountaineers [11]

E. Scenario 1: Mission Analysis

Fig. C1 shows the generic mission phases as a function of altitude and mission time. It contains all essential phases organized in chronological order. As mentioned before, the aircraft requires a distinct climb performance combined with low stall speed. However, from the descent phase it is not a time critical situation anymore and all remaining phases can be flown efficiently. In order to minimize the turnaround time, diving fast could be useful. Thereby, the number of aircraft can be decreased too.

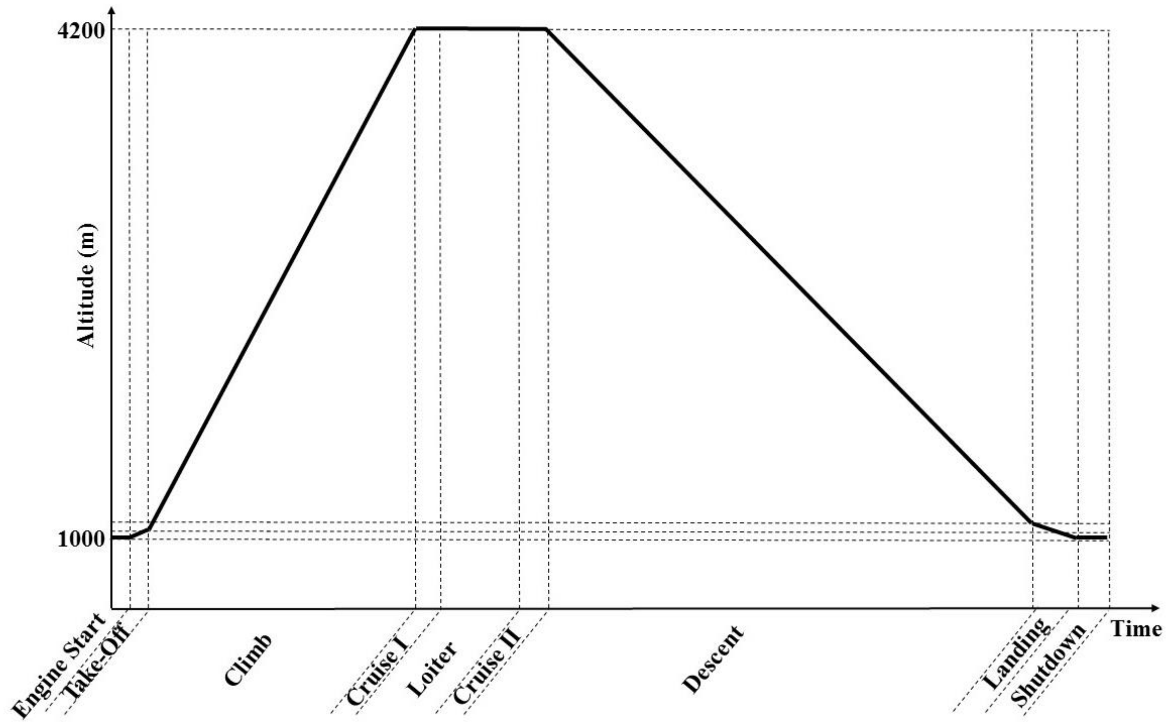

Fig. C1: Mission phases

Based upon the mission plot in Fig. C1, the specific mission requirements and constraints are defined in Table C1. The airspeeds are derived from the limited time available to rescue avalanche victims (Fig. 1) and the distance between take-off site and destination area.

Table C1: Mission definition

Phase No.	Phase Name	Start Altitude	Final Altitude	Vertical Speed	Horizontal Speed	Description	Constraints
1	engine start	1000 m	1000 m	0 m/s	0 m/s	system start	time t_{start}
2	take-off	1000 m	1050 m	4 m/s	v_{TO}	VTO(L) and initial climb	distance $x_{TO} \leq 150$ m
3	climb	1000 m	4200 m	14 m/s	v_{climb} = 42 m/s	fast climb	time t_{climb}
4	cruise I	4200 m	4200 m	0 m/s	$v_{cruiseI}$ = 55 m/s	fast cruise	time t_{cruise}
5	loiter	4200 m	4200 m	0 m/s	v_{search}	search flight	speed v_{search} time $t_{search} = 1$ h STR = 28°/s ATR = 35°/s
6	cruise II	4200 m	4200 m	0 m/s	$v_{eff,\ cruiseII}$	efficient cruise	power demand
7	descent	4200 m	1100 m	10 m/s	$v_{eff,\ descent}$	engine off	power demand
8	landing	1100 m	1000 m	3 m/s	v_{LA}	V(TO)L	distance $x_{LA} \leq 150$ m
9	shutdown	1000 m	1000 m	0 m/s	0 m/s	shutdown refuel/charge	time $t_{shutdown}$

F. Scenario 2: Detailed implementation

In order to define an ambitious benchmark scenario the search for a missing paraglider also takes place in the European Alps. The decision was made for the Swiss Alps due to their challenging terrain combined with a typical airspace structure. In the mentioned scenario the original destination is next to the town of Fiesch.

Location of the last reported point:	46° 23' 15.49'' N 8° 2' 8.18'' E
Original destination:	46° 25' 38.18'' N 8° 5' 36.12'' E

Slightly apart, the town Interlaken provides the required infrastructure for a SAR mission. The location of the probably used airfield is assumed as:

Location airfield:	46° 40' 37.05'' N 7° 53' 18.22'' E

As described in the detailed setting of scenario 1, the hospital and the heliport are very close to the airfield. The hospital is located in the west of Interlaken within a range of 3.5 km and the heliport is also directly neighbouring. In order to reach the search area, which is in a parallel valley to Interlaken, four airspaces of different types have to be taken into account:

- Alpen Mil Off (FL150 – FL195), C
- Meiringen: 130.15 (GND – FL130), CTR
- LS-R9 Reckingen/Gluringen (GND – 37750MSL), restricted
- LS-R9A Reckingen/Gluringen (6000 MSL – 37750MSL), restricted [10]

Fig. D1 visualizes the airspaces. Meiringen 130.15 is marked in yellow, which is in the north west of the flight area. Close to this, the airfield, tagged in red, is located at latitudinal location 40,000 m in the west. Both restricted airspaces are also colored yellow in the middle of the flight area. Airspace C is marked in blue and covers nearly the entire area. The search area is also tagged red in the east of the restricted airspaces.

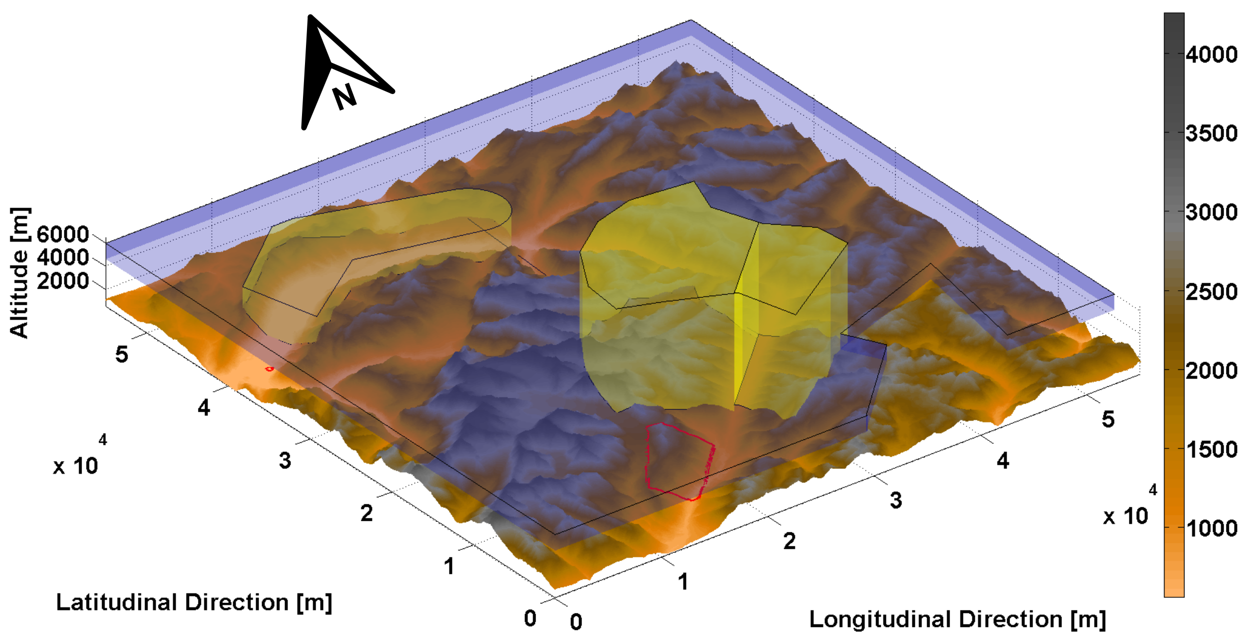

Fig. D1: Flight area with airspaces [10, 11]

G. Scenario 2: Final scenario information

Final required information required are the coordinates of the search area corner points and the crash site which is marked red in Fig. E1. The paraglider is assumed to be alive.

CP1:	46° 26' 22.16'' N
	8° 5' 12.18'' E
CP2:	46° 24' 26.72'' N
	8° 8' 0.61'' E
CP3:	46° 21' 31.34'' N
	8° 3' 43.13'' E
CP4:	46° 22' 41.70'' N
	8° 1' 9.40'' E
Location crash site:	46° 25' 10.87'' N
	8° 4' 30.05'' E

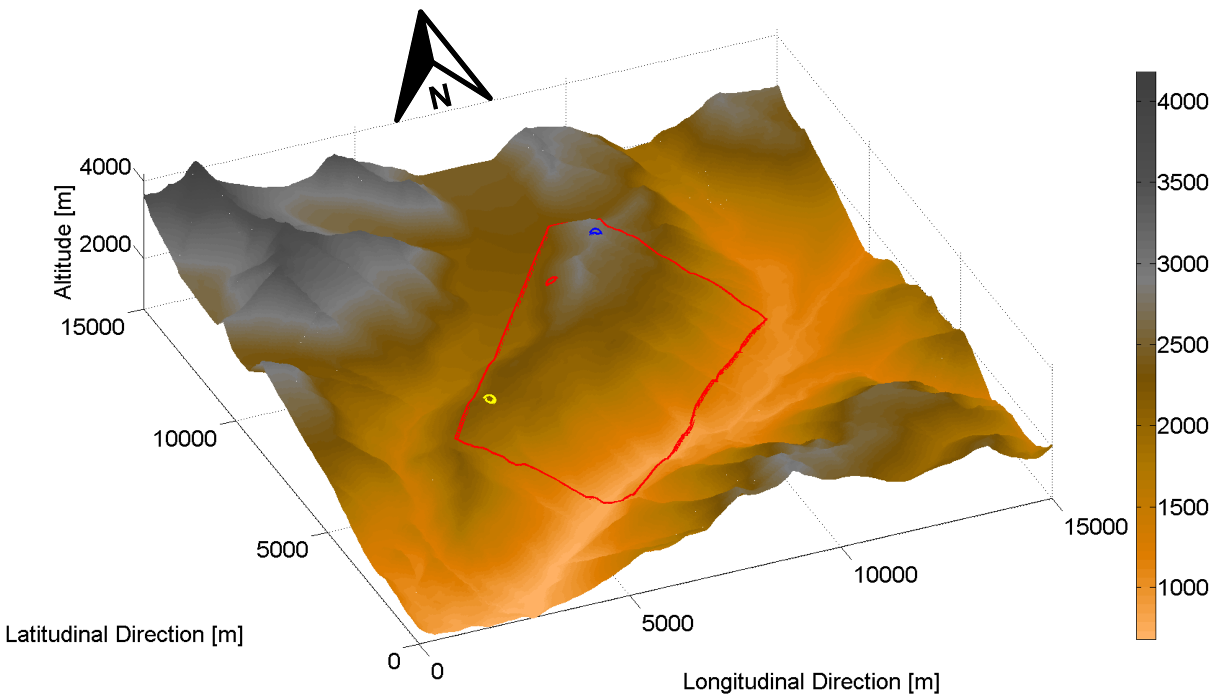

Fig. E1: Search area with crash site [11]

Consequently, a wide search area which extends from the last reported (yellow) in suggested flight direction to the original destination site (blue). All in all, an area of approximately 35 km^2 has to be scanned.

H. Scenario 2: Mission Analysis

Summarizing all mission phases, Fig. F1 displays the mission altitude as a function of mission time. The loiter phase is the most time-consuming one and, with its ending, the remaining phases are not time critical anymore. Table F1 comprises all mission requirements and constraints. The airspeeds are based on the distance between the take-off site and destination area, as well as on the relationship between search area size, sensor resolution, and searching time.

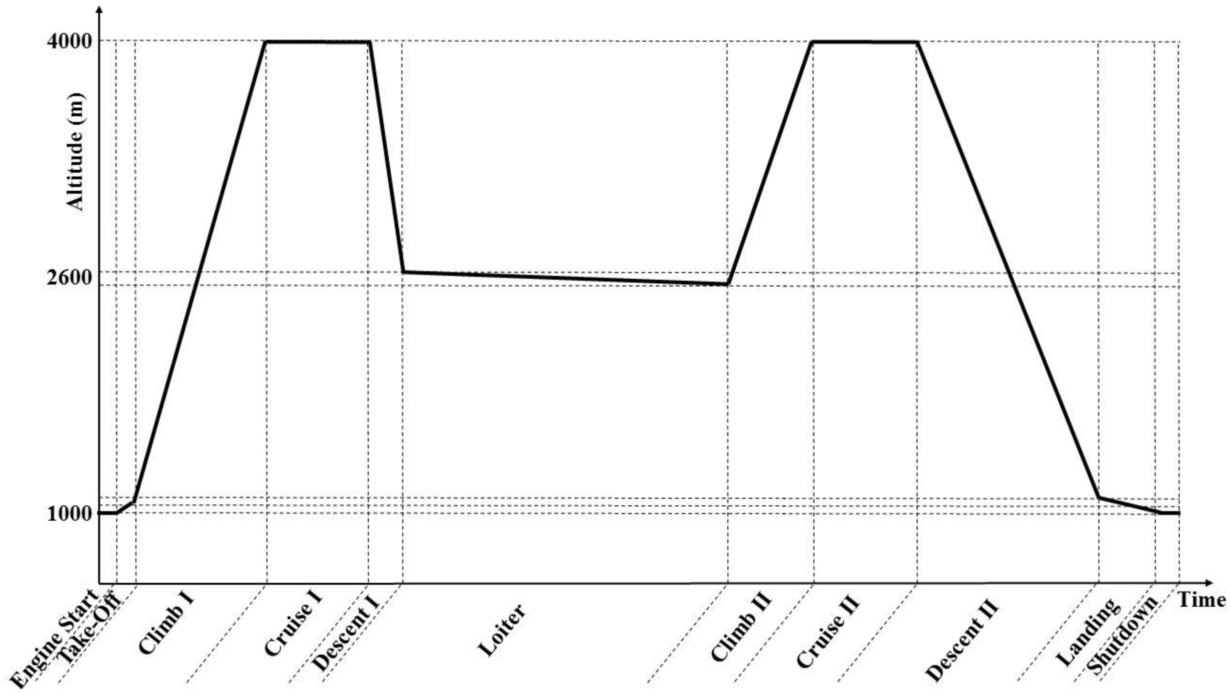

Fig. F1: Mission phases

Table F1: Mission definition

Phase No.	Phase Name	Start Altitude	Final Altitude	Vertica l Speed	Horizontal Speed	Description	Constraints
1	engine start	1000 m	1000 m	0 m/s	0 m/s	system start	time t_{start}
2	take-off	1000 m	1050 m	4 m/s	v_{TO}	VTO(L) and initial climb	distance $x_{TO} \leq 150$ m
3	climb I	1000 m	4000 m	14 m/s	v_{climbI} = 42 m/s	fast climb	time t_{climbI}
4	cruise I	4000 m	4000 m	0 m/s	$v_{cruiseI}$ = 55 m/s	fast cruise	time $t_{cruiseI}$ distance $x_{cruiseI}$ = 50 km
5	descent I	4000 m	2600 m	14 m/s	$v_{dive, descentI}$	fast descent	vertical speed
6	loiter	2600 m	2600 m	0 m/s	v_{search} = 40 m/s	search flight area: (5 km x 7 km) altitude: (1300 m-2600 m)	speed v_{search} time t_{search} = 360 min STR = 28°/s ATR = 35°/s
7	climb II	2600 m	4000 m	10 m/s	$v_{eff, climbII}$	efficient climb	power demand
8	cruise II	4000 m	4000 m	0 m/s	$v_{eff, cruiseII}$	efficient cruise	power demand
9	descent II	4000 m	1100 m	10 m/s	$v_{eff, descentII}$	engine off	power demand
10	landing	1100 m	1000 m	3 m/s	v_{LA}	V(TO)L	distance $x_{LA} \leq 150$ m
11	shutdown	1000 m	1000 m	0 m/s	0 m/s	shutdown refuel/charge	time $t_{shutdown}$